Smoothing the peak

Integrated optimization algorithms save heating costs

HOLGER KRÖHLER, ANDREAS SCHADER, REINHARD BAUER, SILKE KLOSE, SUBANATARAJAN SUBBIAH – Many industrial processes use large amounts of heat generated by electricity. This can be expensive, and even more so if significant quantities of peak power are consumed. ABB's new DCT880 is a thyristor power controller for heating applications whose integrated power optimization algorithms reduce costs by reducing peak power demand. This is done fully automatically without affecting the production process or schedule. The main component is an optimization suite that runs on the DCT880 without the need for further supervisory equipment like additional programmable logic controllers. The key to optimization is a microtime energy scheduling algorithm. This shifts the periods in which energy is consumed by amounts small enough that the heating process is not affected. However, by cleverly applying those changes, the peak power demand can, in many cases, be greatly reduced.

1 The DCT880's power optimization algorithms help users avoid expensive peaks in their power consumption.

A significant cost factor in all heating applications is energy. When heating electrically, the total energy cost is often greatly increased by the extra cost of power peaks. Such cost penalties are very common for larger customers as it helps to keep the grid and power production stable. This penalization strategy is becoming more prevalent as more renewable power generators join the grid.

One way to decrease the peak consumption would be to distribute energy-intensive process tasks evenly over the day. However, this approach would not prevent peaks that occur over a smaller timescale. The DCT880 offers a different solution – it distributes the load to maximize peak reduction ➔ 1. In this way, the DCT880 can cost-optimize thyristor control of resistive, inductive and infrared heaters in annealing, drying and melting, and of heating in the glass, plastics and metal industries.

Title picture
Peaks in any sense set a challenge. A mountain peak is simply there and must be scaled. However, the sophisticated power optimization algorithms in ABB's DCT880 help users avoid expensive power consumption peaks in the first place.
Photo credit: Michelle Kiener.

General setup

Many industrial heating applications consist of numerous heating elements at the same site. These heating devices may have different energy consumptions when switched on; some may operate in a coupled manner; and they could all be controlled by one supervisory control or independently by local PID controllers.

Regardless of which setup is actually used, one requirement is ubiquitous: good power quality. This can be achieved by using full-wave burst firing, ie, by either letting full sine waves pass or by completely blocking them to switch the device fully on or off ➔ 2. When doing power optimization, the DCT880 uses full-wave burst firing. Besides this mode, the DCT880 also offers other control methods like half-wave control, soft starts and soft downs as well as phase-angle control ➔ 3.

> The challenge with the DCT880 was to bring high-quality discrete optimization routines to a unit with relatively little computational power.

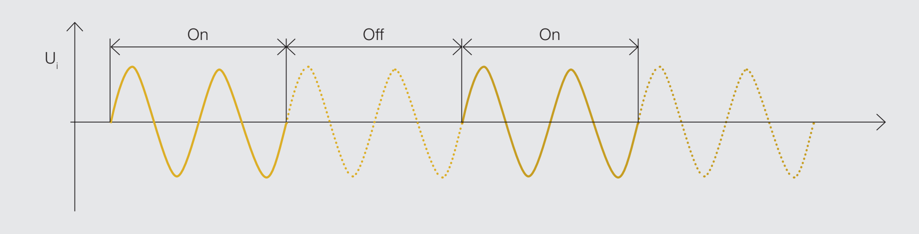
A heating application is often subdivided into cycles that are between 2 and 20 s long, with each cycle controlled independently. Directly before the start of a new cycle, sensor measurements are made and – for each heating device – the amount of energy to be distributed throughout the next cycle is calculated. Knowing the operating power of the heating device, it then is easy to calculate the length of the next cycle. The overall heating process is slow enough that it does not matter exactly when during the cycle the energy is distributed (ie, when the heating device is switched on).

Depending on the load type, each DCT880 can control up to three loads that are independent of each other. Many configurations are possible, such as several single-phase, delta, star, multi-tap, open delta, etc. If more than three loads are to be controlled, one (standard) DCT880 will act as master and will be responsible for the power optimization calculations. Any DCT880 can be made master by setting a software switch. However, there may be only one master per system ➔ 4.

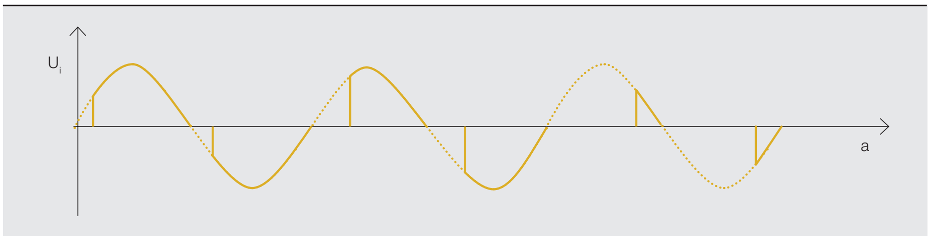
After a DCT880 receives the information on the energy demand of its load for the next cycle, it passes that information to the master.

When heating electrically, the total energy cost is often greatly increased by the extra cost of power peaks.

2 Full-wave burst firing



3 Phase-angle control



When the master has received this information from all its slave DCT880s, it performs the optimization step – ie, calculating when to switch each heating device on and off so as not to negatively affect the heating process. The results are then passed to the slave DCT880s so they can control their heating devices in the next cycle.

How is optimization done?

The diagram in → 5 demonstrates the dramatic difference power optimization makes. When the DCT880's optimization takes charge, the curve volatility disappears and the curve becomes much smoother, never exceeding 50 percent of the installed capacity. How can this be achieved?

The principle is illustrated in → 6. In → 6a eight heat consumers are shown that have 100 kW and 200 kW operating powers and a utilization between 30 percent and 70 percent over the 1 s cycle time. → 6b shows that the accumulated power consumption is uneven, with a peak after 300 ms.

→ 7 shows the same situation, but with a mathematically optimal solution. The periods in which the consumers are switched on are perfectly distributed across the cycle → 7a. No peak exists in the overall demand → 7b.

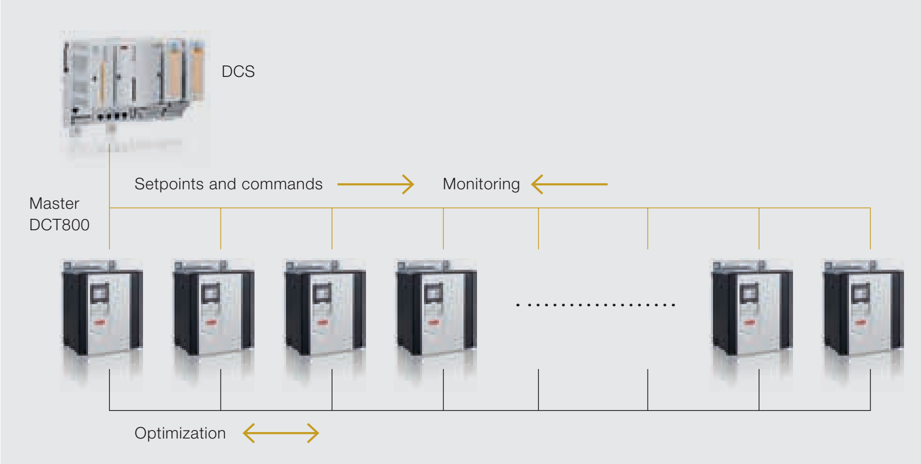
A special feature of DCT880's power optimization is its handling of mid-load situations. In → 8a all devices are working at 60 percent utilization of the cycle time so no matter which consumer switching strategy is chosen, there will be a peak somewhere → 8b. The problem can be overcome by splitting – ie, switching a consumer on and off twice during the cycle → 9. Splitting is the only way to achieve this perfect solution.

To save cost, the approach should be able to run on a DCT880 alone – without any additional equipment. It also has to be fast enough to service small cycle times and accommodate different types of input.

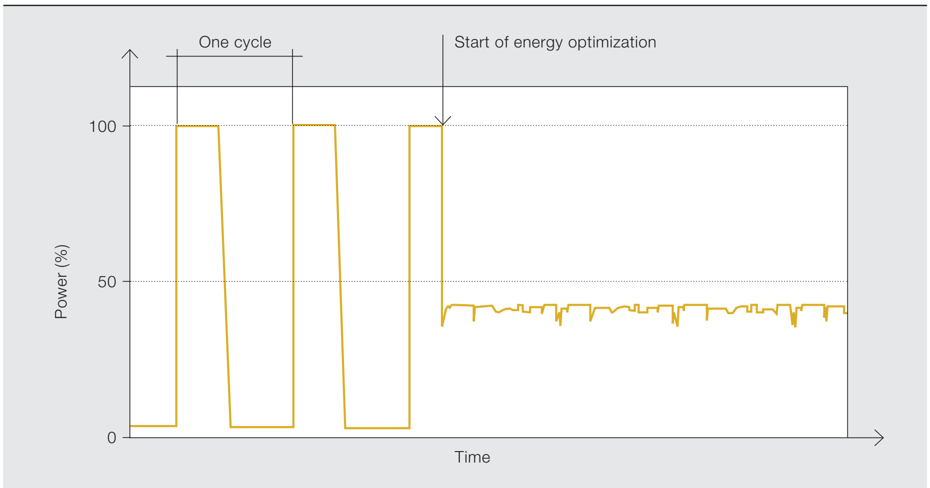
The approach: algorithm engineering

From a mathematical perspective, the underlying problem belongs to the field of discrete mathematical optimization. This is a very mature field of research, already offering a rich toolbox to support the algorithm development, in which ABB has extensive expertise.

4 Communication architecture of the DCT880



5 Energy consumption (relative to the sum of the power of all heaters) of an installation with 14 consumers without (left half of graph) and with (right half) power optimization.



The DCT880 distributes the loads to reduce peak consumption.

Mathematical optimization is often performed on dedicated high-performance computers. The challenge in the case of the DCT880 power optimization was to bring high-quality discrete optimization routines to a unit with relatively little computational power. The decision was made to apply the methodology of algorithm engineering: In a cycle consisting of design, analysis, implementation and experimental evaluation, custom-tailored, practicable and very efficient algorithms were developed that perfectly fit the available capabilities. Each algorithm considered was tested on data originating from a real-world installation.

Algorithm engineering is an iterative approach. After a new algorithm has been evaluated, it can become the new base for further development, can be discarded or can be revisited, depending on the measured quality of the approach. A sequence of solution algorithms with increasing quality is thus obtained.

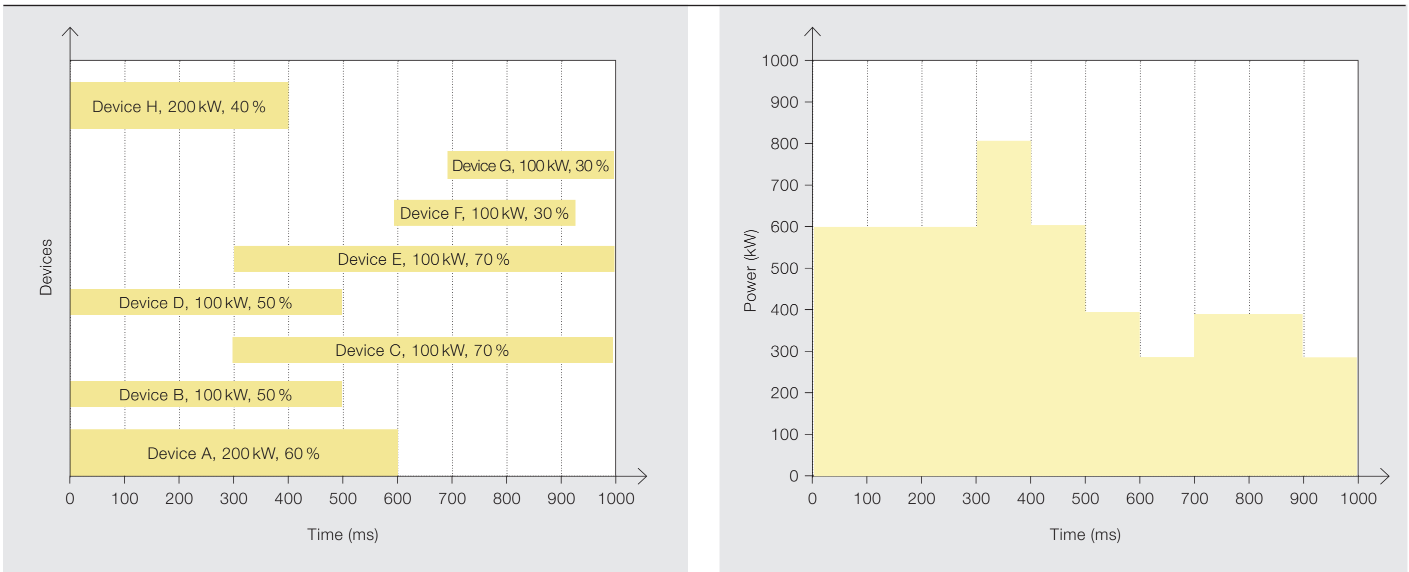
However, after reaching a satisfactory quality level only half the work is done. The next step is to make the algorithms simple and easy to work with. Again, using an iterative approach, the existing algorithms are improved.

Solution quality is not allowed to deteriorate. However, new algorithms should be simpler and easier to maintain than their predecessors. This way it is possible to satisfy the two, often conflicting aims of solution quality and maintainability.

Making algorithms for the real world

In order to develop a solution that succeeds in a real-world setting, many additional requirements have to be met. Technical restrictions may lay down a minimum operating duration for a heating device. The number of switching actions within one cycle may also be limited. Further, a restricted grid connection may necessitate load shedding: If the

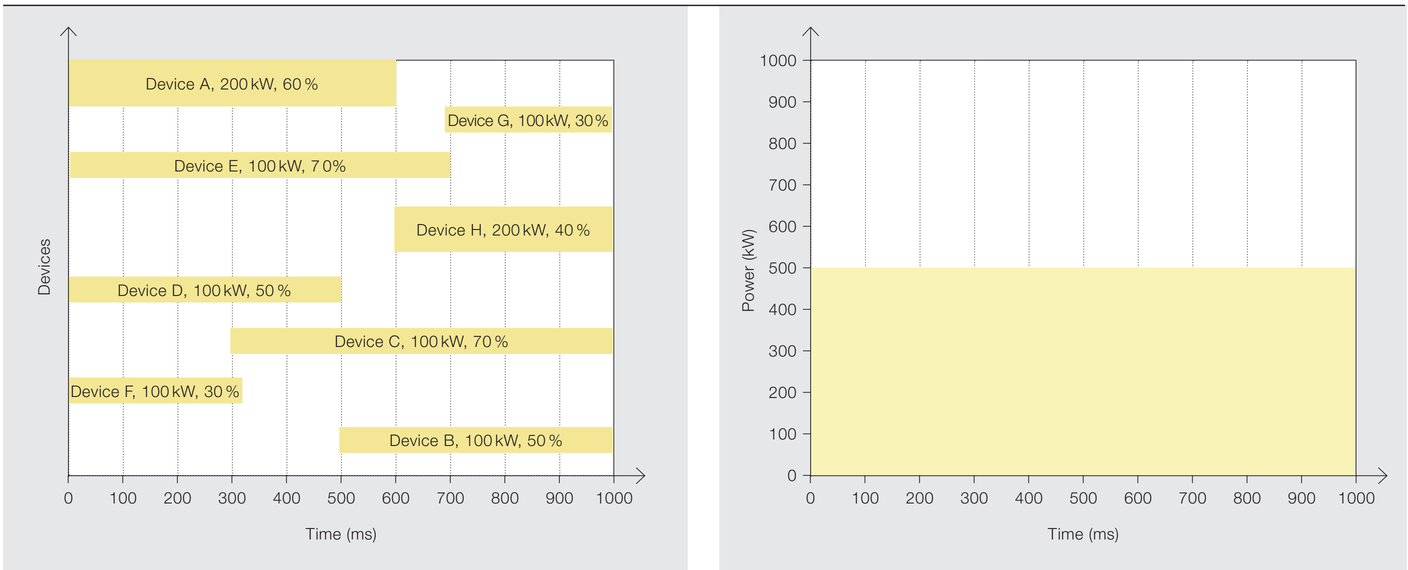
6 Nonoptimized power consumption



6a Eight consumers spread over a 1 s cycle

6b After 300 ms, power consumption peaks

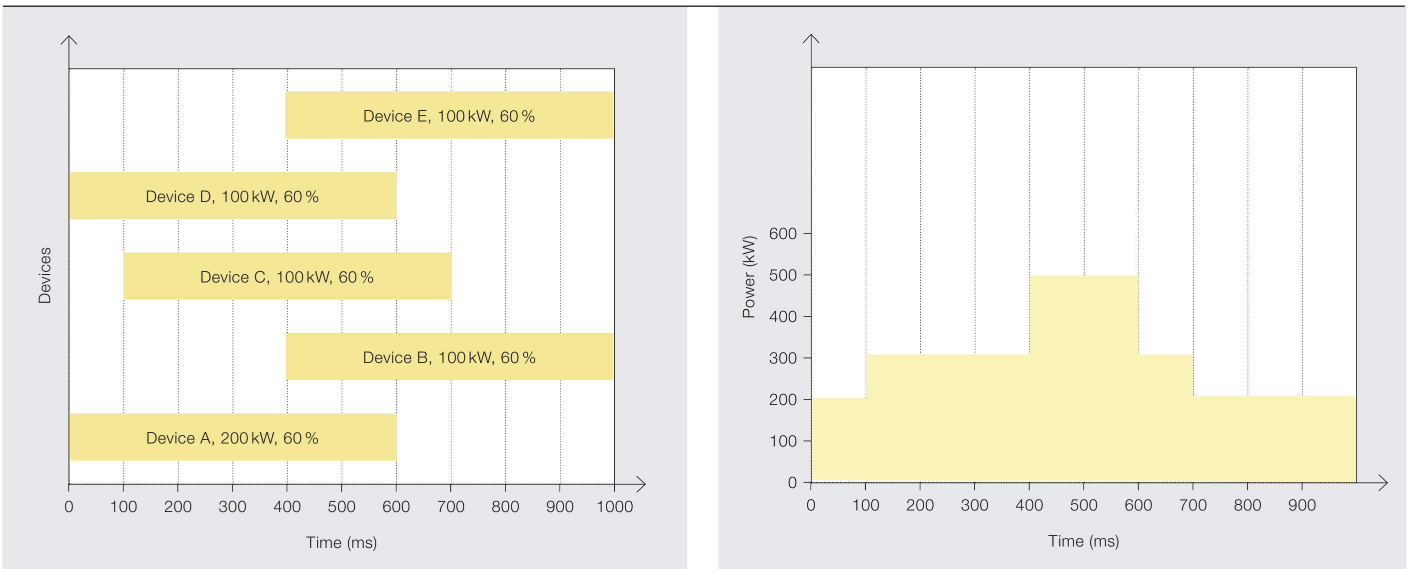
7 Optimized solution



7a Consumers are distributed across the cycle.

7b The optimal distribution of the consumers means that no power peaks are present.

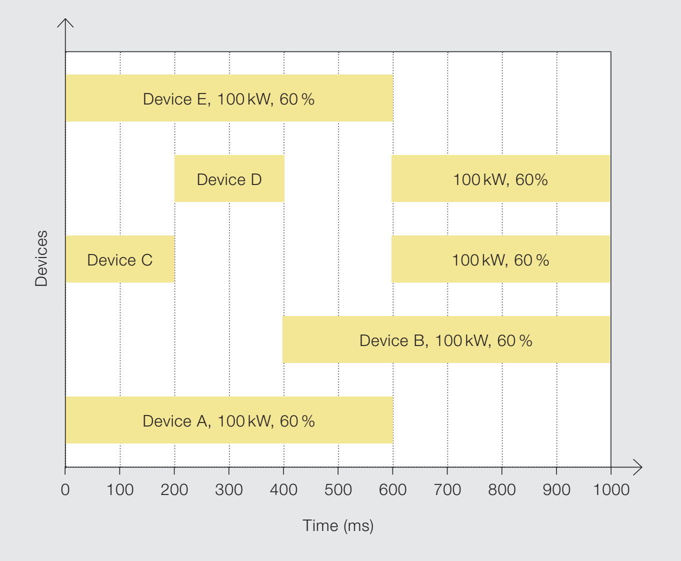
8 Mid-load situation



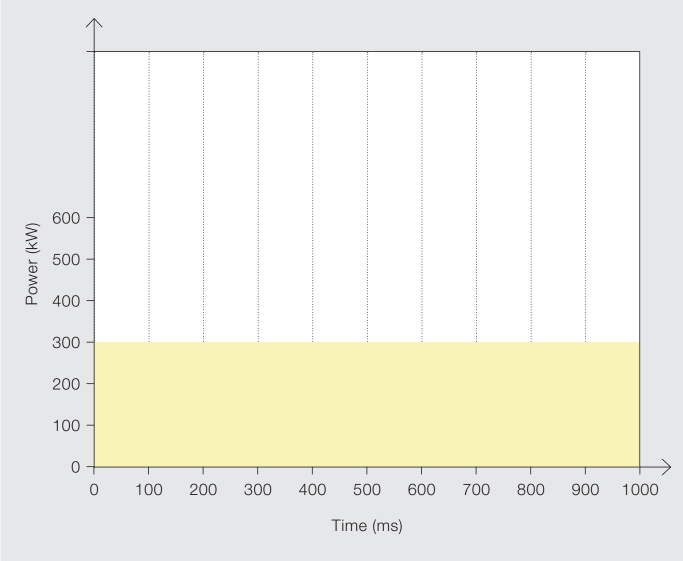
8a Loads may occupy a large portion of the cycle.

8b A peak somewhere is inevitable in mid-load situations.

9 Load splitting



9a During the cycle some consumers can be switched on and off twice.



9b Splitting is the only way to reach a perfect solution.

In a cycle consisting of design, analysis, implementation and experimental evaluation, custom-tailored, practicable and very efficient algorithms were developed.

heating devices' collective power demand exceeds the power the grid connection can provide, emergency shutdowns should be performed by some devices.

Further, to reduce costs for the customer, the approach should be able to run on a DCT880 alone – without any additional equipment. It also has to be fast enough to service small cycle times and accommodate different types of input.

With all these constraints, the solution should still be easy to handle and maintain. To that end, a solution was developed that does not need a mass of tuning parameters and options understood only by experts.

Benefits of the new solution

The DCT880 optimization solution reduces the customer's process energy costs. It also helps to enforce grid stability and power quality. It is easy to use as it dispenses with hard-to-understand tuning parameters, which means commissioning and maintenance can be done without the aid of specialists.

A further significant advantage of the solution is its architecture: The optimization is performed completely separately from the rest of the setup – ie, all units report their set points to the master unit and receive optimized commands in return. Hence, the optimization can be integrated into any setting – it does not matter if there is a supervisory control programmable logic controller (PLC) or if each DCT880 is controlled locally by a separate controller.

Further, the production process is not affected by the optimization routine so there is no need to adapt operational planning.

On the market

Development of the DCT880 – which is based on proven and reliable ABB DCS DC drive technology utilizing ABB's new control platforms, ACS880 and ACS580 – started in early 2013. The product and the power optimization algorithms were launched in late 2014.

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